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Modern Science and Technology: Differentiation or Interpenetration?*

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Introductory Remarks

FOR US, NOWADAYS, the concept of technology as the application of general theory to the solution of practical and specific problems, and at the same time a particularly close relationship between science and technology, has the quality of a well-known fact. Looking back through history and comparing cultures, this is not quite as obvious as it seems to us today. And there are still major differences to be found as far as the relationship between scientific theory and practical technology is concerned, even among those societies that are regarded as part of modern Western culture—England, France, Germany and the United States, for example. Historically and interculturally, the concept of technology as applied theory is a feature of modern Western culture, or, to be more precise, a feature that originated in Europe in the culture of the Italian Renaissance of the 15th and 16th centuries. We need only think of the achievements of India and of Hellenism to realize that theoretical abstraction had been even more highly developed outside Western Europe before the Renaissance. The same is true for sophisticated technology, the prime example here being China with the many inventions it had long before the West. However, before the European Renaissance, a comparable linking of theory and technology and the thought of technology as theory in application had not existed anywhere outside Europe. This observation is to be found in Max Weber's (1972a: 1-2, 10-11, 414-416, 435-443, 481-484; 1972b: 143-147, 162-169; 1973: 595-598) comparative studies on the development of modern Western culture. After Max Weber it was, more than anyone else, Edgar Zilsel (1942a, 1942b, 1945) who showed this in his work on the social origins of modern science. Others, like Bernal (1967), the Marxist-oriented historian of science, or Joseph Needham (1954, 1969), the well-known sinologist, see the proximity of theory and practice, science and technology as something

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decisively new that has distinguished modern Western culture from other cultures since the Renaissance. It can therefore be said that the particularly close relationship between scientific theory and technology in modern Western culture is a generally accepted historical fact.

Things start to look a bit different, however, if we apply a perspective widely accepted among sociologists that says that the development of modern societies is characterized by an increasing differentiation and rationalization of social spheres according to their own laws (Habermas, 1981; Luhmann, 1970, 1976, 1980; Schluchter, 1976, 1979). Applied to the subject in hand, this would mean the increasing social differentiation of theory and technology and their autonomous rationalization i.e. the increased abstraction of theory and the increased practical specification of technology. According to the theory of functional differentiation, both subsystems should thus be able to increase their efficiency to benefit the societal system of which they are a part. The trouble here is that the question of the necessary mutual interchange of services is usually ignored. That this interchange is disproportionately the more important problem is seen in the fact that non-Western cultures have also reached the stage of mere functional differentiation but not that of interchange. There were indeed decisive barriers that made interchange of the kind between theory and technology quite impossible. It can be shown that the difference between the world's most highly developed society, theoretically and technically, the United States, and the societies of Europe that it has overtaken is not so much the degree of differentiation of theory and technology as the degree of their interchange. I wish to refer to this as interpenetration, as mutual penetration, as a specific form of the relationship between social systems to distinguish it from other more one-sided or more isolating forms such as adaptation, domination, mutual isolation or reconciliation.

I do not claim to have a supply of new *facts* that surpass the knowledge we have from well-known historical studies (e.g. Bernal, 1969; Ben-David, 1971; Boas, 1970; Butterfield, 1965; Crombie, 1971; Finch, 1961; Hall, 1959; Merton, [1938] 1970; Nelson, 1968; Rossi, 1970; Whyte, 1962; Zilsel, 1942a, 1942b, 1945). My aim here is to relate historical interpretation and explanation more closely to sociological theory than is usually the case and to *reinterpret* known historical facts in the light of a theory of interpenetration. This distinguishes itself particularly from theories of pure differentiation and rationalization but also from other one-sided theories that explain the development of science and technology in purely economic, power political, normative or idealistic terms.

1. *The Theoretical Frame of Reference*

What I am concerned with here is how to explain the extent and development of the mutual penetration of *theory* and *technology*, *logical* and *empirical proof* when compared inter- and intraculturally. To answer this question we need a general theoretical frame of reference providing an analytical perspective for

the consideration of our subject matter. What is required is an ordered model of analytically distinguishable factors, the particular contribution of which explains the particular dimensions of modern science and technology. We have to subsume under this frame of reference those initial historical conditions which allow us to assume that the contributing factors required for the production of particular structures (e.g. the interpenetration of theory and technology) are given or are not given. The theoretical model I want to use to solve these problems is based on an application of Parsonian voluntaristic action theory (Parsons, 1968a, [1937] 1968b, 1977, 1978; Parsons and Platt, 1973; Alexander, 1982; Münch, 1980, 1981, 1982a, 1982b). The interpretation of action theory has to be as comprehensive as possible in order to allow for the inclusion of more specific approaches like economic theory, conflict theory, Marxist theory, symbolic interactionism, ethnomethodology and Habermas' theory of communicative action. In that wider-ranging frame of reference the scope and the validity of these particular approaches can be determined. But I am not concerned with proving this assertion here. What I want to demonstrate is how to apply this comprehensive voluntaristic action theory by specifying it to a theoretical model for the explanation of the specific dimensions and interrelationships of modern science and technology.

My starting-point is a particular interpretation of the well-known AGIL scheme and my first step is using it to distinguish the dimensions of modern technology. This way, our subject matter is *defined*. The second step is the explanation of the inner dimensions of modern technology by its interrelation with aspects of science. The third step is the explanation of the wider-ranging dimensions of modern science and technology by the relationship between them and the factors surrounding them but closer to the extreme poles of the action space constituted by the AGIL scheme.

Thus I will first discern the dimensions that I assume to be interrelated and unified in modern technology to a higher degree than in non-modern and non-Western cultures. Looking at science and technology as it emerged from the European Renaissance onward, this is only relatively, but not absolutely, true. In order to explain this, let us now turn to a brief introduction of the relevant interpretation of voluntaristic action theory.

I will try to locate modern science and technology in the action space which can be construed by the interrelation of the two basic elements of any action system: symbols (meanings, norms, expressions, cognitions) and action guided by these symbols. Of primary interest on the most abstract level of theorizing are the varying degrees of order within an action system constituted by the relationship of symbols to actions. Symbolic articulations can vary from lowest to highest complexity defined by the number of symbols and the number of their interrelations. Action directed by symbols ranges from lowest to highest contingency defined by the number and the interrelationships of actions open to an actor in a situation. Analytically, symbolic complexity and contingency of action vary independently from the lowest to the highest degree, thus yielding various forms and degrees of orderedness of action. The nature of

ordered action varies between four extreme poles and four corresponding *fields* of action:

A. *Adaptation.* Increased symbolic complexity and increased contingency of action constitute the field of adaptive action. This changes from situation to situation and is guided by the principle of the optimization of a set of ends by distributing means to these ends. There are no limits on imagination and articulation of symbols and no limits on the interpretation of symbols and on action in response to symbols. Learning and exchange within market structures lead action into this field thereby *opening* the scope of action. This is the domain of economic theory.

G. *Goal attainment.* Increased symbolic complexity and decreased contingency of action form the field of goal-directed action. It is determined by specific ends according to the principle of the realization and maximization of one single end. Whatever may be imaginable, the interpretation of symbols and action are reduced to one and only one specific interpretation and action. Affectual bonds between individuals and ends, power available to pursue these ends or external enforcement by power and authority lead action into this field. Their function is the *specification* of the scope of action. This is the domain of conflict theory.

I. *Integration.* Decreased symbolic complexity and decreased contingency of action construe the field of structured and regularly expectable action. This action is committed to norms, independent of changing situations and ends and is guided by the principle of conformity. Action is determined by a small set of symbols and every symbol has a definite meaning, allowing for one and only one interpretation and action. Tradition and the affectual commitment to self-evident, shared norms (Lebenswelt) within a solidary community lead action into this field. Their function is the *closing* of the scope of action. This is the domain of normative approaches such as phenomenology, ethnomethodology and symbolic interactionism.

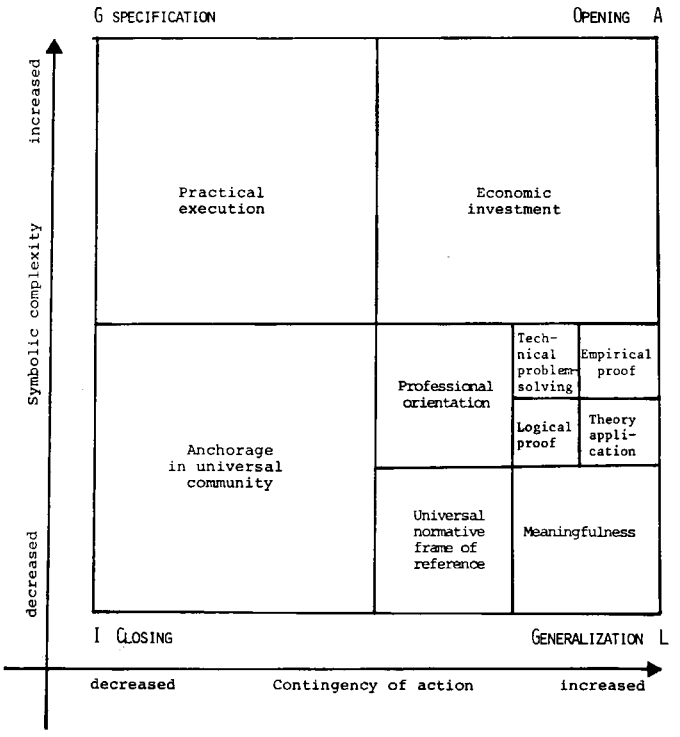
L. *Latent pattern maintenance.* Decreased symbolic complexity and increased contingency of action form the field of identity of action that maintains an identity beyond time, changing situations and varying performances. Action is directed in this case by general ideas according to the principle of consistency. There is only a small set of binding symbols imaginable but their generality allows for a great variety of interpretations and specifications to actions. Symbolic frames of reference and discursive procedures lead action into this field. Their function is the *generalization* of the scope of action. This is the domain of cultural idealism.

2. *Application of the Frame of Reference in Distinguishing Dimensions of Science and Technology*

The first application of the frame of reference of voluntaristic action theory serves here as a technical tool in distinguishing dimensions of modern technology (Diagram 1). We can discern structural forms of action aimed at

Diagram 1

The Dimensions of Modern Technology



technical problem solving. We begin with an interpretation of technical problem solving as a cultural activity removed from immediate practical action. It is primarily oriented to cognition and, to a lesser degree, to norms, expressions and meaning. Within this cognitive orientation the function of technical problem solving is the specification of knowledge in order to achieve particular ends. Technical problem solving is the specificative component of cognitive cultural activity (L_{A_G}). But, as I have said, a peculiarity of modern Western technology is the inclusion of science in technical problem solving. Thus technical problem solving (L_{A_G}) is in close interrelationship with logical proof (L_{A_I}), empirical proof (L_{A_A}) and the application of theory (L_{A_L}).

If we look beyond the relationship between science and technology on the level of the socio-cultural aspect of action, we can also designate the inclusion of further socio-cultural attributes as a peculiarity of modern technology: the orientation to questions of the meaningfulness of the relationship between man and the objective and technically transformed world (L_L), the commitment to a universal normative frame of reference defining norms for technical problem solving (L_I), and professional orientation (L_G).

If we look beyond the aspect of socio-cultural action, modern technology is characterized by the further inclusion of the following aspects: the anchoring in a universal community and not only in particular carrier strata (I), technical development through economic investment (A), and practical execution of theoretical problem solving (G). Without these last two attributes, technology remains reduced to the level of non-realizable models, as in the papers of medieval artists like Leonardo da Vinci, a way ahead of their practical realization.

Modern technology is, in its intimate links with science and its interrelation with the other aspects of human action, far from being reduced to a one-dimensional phenomenon. The development of modern technology can therefore not be conceived as a process of one-dimensional rationalization and differentiation from other subsystems of action. Neither can it be explained by some inner laws of technical rationalization, nor by laws of the differentiation of purely specialized subsystems of action due to pressure resulting from the increasing complexity of the environment of action systems. Assuming that this is true, the explanation of the structure and development of modern science and technology does not call for a theory of rationalization and pure differentiation but for a theory of the interpenetration of different subsystems of action. But to avoid any misunderstanding, let me reiterate that this is the feature that distinguishes modern science and technology from that of pre-modern and non-Western cultures. I am in no way asserting that this is absolutely true for modern science and technology and that there are no serious deficits in the linking of pure technical problem solving with the structures in its environment.

3. *Application of the Theoretical Frame of Reference to the Explanation of Attributes of Modern Science and Technology: General Theoretical Relationships*

I will now proceed to apply our theoretical model of action in order to formulate hypotheses on the conditions governing the emergence of the designated aspects of modern science and technology. The AGIL scheme is used here to differentiate those structures of action the interrelation of which with technical problem solving serves to explain the various attributes of technology. The basic assumption here is that the various attributes of technology, defined by their location in the action space, have to be explained by a specific form of interrelation with those environing subsystems of action located in the same dimension and field of the action space but closer to the outer poles. The specific interrelation required is the interpenetration of technical problem solving with its environing subsystems and structures of action. I distinguish between this and the domination or over-steering of technical problem solving by the environing subsystems, the domination or over-steering of environing subsystems by technical problem solving, integrated or disintegrated underdevelopment of both sides and conflict, mutual isolation, or reconciliation between the subsystems. In the case of the domina-

tion of a higher ordered system, we speak of the constriction of the lower ordered systems; in the case of the domination of a lower ordered system, we speak of the accommodation of the higher ordered to the lower ordered system. The occurrence of these various interrelations is dependent on the degree of one-sided development of one subsystem without intermediate subsystems (domination, constriction, accommodation) or with intermediate subsystems (over-steering), the equal underdevelopment of subsystems without intermediate subsystems (malintegrated underdevelopment) or with intermediate subsystems (integrated underdevelopment), or equally high development of subsystems without intermediate subsystems (conflict) or with intermediate subsystems. In the latter case we have to distinguish between interpenetration, mutual isolation and reconciliation.

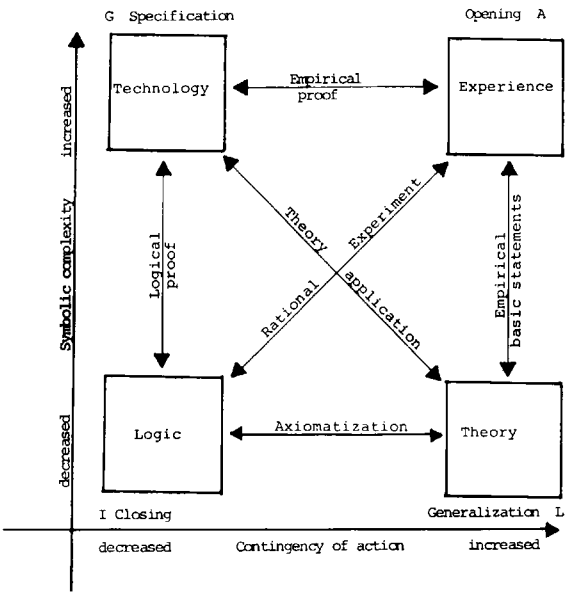
According to our model, particular attributes of technology, located in a specific dimension of the action space, can only emerge through interpenetration with subsystems and structures located in the same dimension but closer to the poles. Technology cannot acquire a normatively binding character through increased economic investment in technical projects or increased inducements for technical inventions. It cannot obtain meaning merely through practical execution and enforcement. By applying the theoretical model of the analytical order of subsystems of action, we can designate the structural forms of action with which technical problem solving must be connected for particular aspects of technology to emerge.

Our first step is to consider the relationship between technology as the specification of scientific theory ($^{L}A_{G}$) and the other subsystems of science (Diagram 2). Technology as the application of theory to specific problems requires the interpenetration of technical problem solving and theory construction. Thus the application of theory to specific problems constitutes a zone of interpenetration between theory and technology (L-G). A zone of interpenetration between technical problem solving and logical proof is formed by procedures involving the rational proof of technical instruments (I-G). Procedures involving the empirical proof of technical instruments are a zone of interpenetration between technical problem solving and empirical research (G-A). The rational experiment, that particular invention of the Renaissance and the cradle of modern science, can be conceived as a zone of interpenetration between empirical research and logical proof (I-A). Empirical statements, i.e. experience in the light of theory, can be seen as a zone of interpenetration between empirical research and theory (L-A). The zone of interpenetration between theory and logic is construed by the axiomatization of theory according to logical relationships (L-I). In each case, the structures in the zones of interpenetration are first produced by combining diametrically opposite structures. Then, as existing structures, they provide for the ongoing interpenetration of opposing structures.

If we wish to explain theory application, logical proof and empirical proof as aspects of technical problem solving, we can (according to our theory) expect these attributes only if technical problem solving interpenetrates sufficiently

Diagram 2

Technology in the Scientific Context

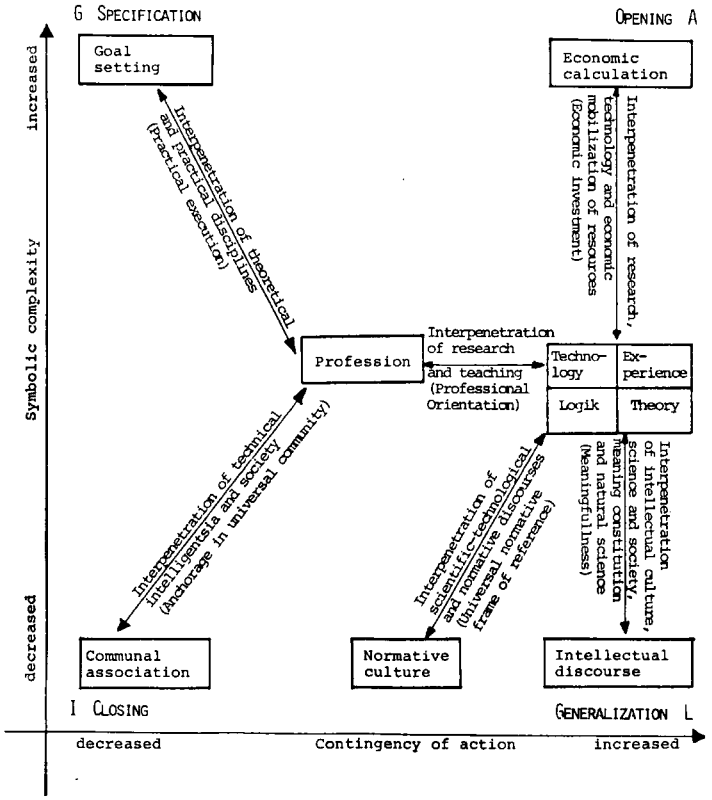


with theory, logic and experience and if these themselves mutually penetrate one another. That this is not self-evident can be seen in the fact that only the Italian Renaissance brought these various forms of knowledge formation close to one another (Weber, 1973: 595-598; Zilsel, 1942b). Outside this Western cultural context, either one form of knowledge dominates the others or they are mutually isolated or merely reconciled without actually influencing each other.

Our next step is to explain the other socio-cultural attributes of modern technology through the interpenetration of technical problem solving with the relevant structures of socio-cultural action in the same dimension of the action space (Diagram 3). Meaningfulness is attributed to technological action through the interpenetration of technical problem solving (natural sciences) and cultural discourse (humanities) if technically oriented discourse connects them (L). The more cultural discourse and technical problem solving develop separately the greater is the tension between them. A universally binding normative frame of reference will exist for the solution of technical problems provided technical action and normative discourse on the basic norms of social life mutually penetrate each other through *practically oriented* normative discourse connecting questions of meaning, scientific and technical questions and the commitment to a comprehensive community that by far surpasses the limits of intellectual and technical strata (^{L}I). If this is not the case and both subsystems develop separately there is a gap between technical and moral life. How dif-

Diagram 3

Science and Technology in the Social Context



ficult it is to bring both subsystems closer together can be seen in the seemingly widening gap between value discussions and technical developments in our own day and age. A further attribute of technical problem solving is the professional orientation of technical experts (^{L}G). This attribute unites a number of different attributes (Parsons, 1968a): (1) the scientific grounding of technical expertise provided by scientific training ($^{L}G_{A}$), (2) the commitment to a normative frame of reference (the ethos of technical experts) ($^{L}G_{L}$), (3) the bond between a universal community and technical experts as the carriers of technological development not confined to purely technical strata ($^{L}G_{I}$), and (4) the orientation to clients' practical goals ($^{L}G_{G}$). All these components must be mediated by the professional expert in his solution of technical problems. The institutionalization of this mediation in a professional attitude requires the commitment of the expert to a profession as the carrier of a specific professional

ethic. Professional action is then embedded in an emergent structure of its own, that is not the same as the various components combined in it.

If we now move on to those attributes of modern technology that are located closer to the extreme poles of the action space, we have to consider the interpenetration of technical problem solving with subsystems and structures near the extreme poles. This interpenetration is not a self-evident one, either. Thus, many technical inventions never left the level of mere ideas because they did not receive the necessary investment of economic resources. This calls for the mutual penetration of economic orientation and technical invention, the providing of economic incentives for investment in technical developments (A). The technical development of the Industrial Revolution cannot be explained without the co-operation of inventors and entrepreneurs, nor without the institutionalization of patent rights. The history of the steam engine is a good example of this (Scherer, 1965). The same is true for the practical application and implementation of technical inventions. They are not possible without the linking of ideal technical planning with the practical setting of goals (G). Only in this way can technical solutions be brought step by step closer to practical goals and, conversely, natural practical particularism can only be overcome through the binding of goal realization to generalized technical models. This gap was also only closed step by step in modern Western culture. Finally, it is vital for the institutionalization of technical action and its products as socially binding that the normative framework of technology is tied to carrier strata (I). The question here is, 'Is technology only carried by a particular societal group, the technical intelligentsia, and are other groups alienated from technology or is it anchored in a more comprehensive cultural community?'. In the latter case, it is necessary for the technical intelligentsia to be integrated with the other societal groups. This requires the various societal groups to share a common socialization in integrated educational institutions, which is more the case in the United States than in the European countries (Ben-David and Zloczower, 1962; Riesman and Jencks, 1968; Schelsky, 1970; Smelser, 1974).

4. *Application of the Theory to the Explanation of Historical Forms of Science and Technology*

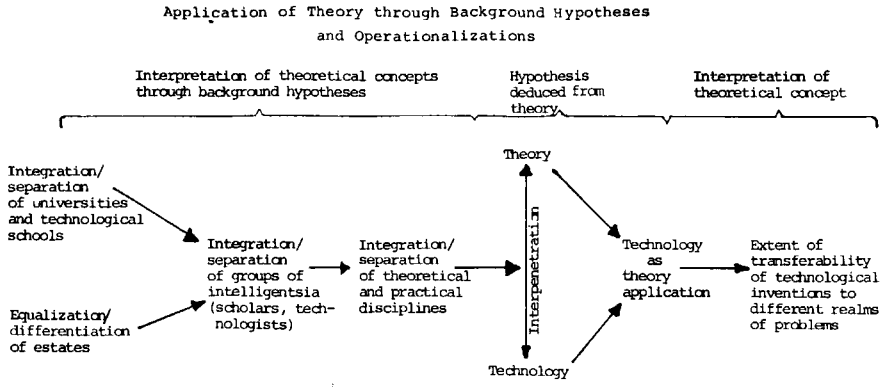
I shall now examine the application of the theory in order to explain the emergence of those attributes of modern technology discussed above and their relations with the attributes of modern science in different cultural and historical contexts. The demands of time and space being what they are, it will not be possible to sketch in every detail. I distinguish three steps in the application of our theory:

— Firstly, we have to discuss, in a cultural comparison, the causes preventing a comparable interpenetration of technical problem solving with theory, logic and systematic experience and all the other non-technical subsystems and structures in the highly-developed cultures of China, India and Hellenism.

— Secondly, a description is needed of the causes that decisively favored the interpenetration of theory, logic, systematic experience and technical problem solving and their interpenetration with the other subsystems and structures of action in the Italian Renaissance in the 15th and 16th centuries and in England in the 17th century.
— Thirdly, we have to consider the factors that characterized the interrelationship of science and technology and their interrelationship with the wider societal context in those societies that successively took a particularly leading role in the development of science and technology: France in the 18th century, Germany in the 19th century, and the USA in the 20th century.

In this process, particular and more or less enduring structures of a particular society will be interpreted as the initial conditions of the theoretical model. I will examine the question of how a particular structural attribute of a society was favorable or unfavorable to the interpenetration of theory and technology and pushed their interrelationship in the direction of accommodation, constriction, domination, over-steering, conflict, mutual isolation, reconciliation or interpenetration (Diagram 4). Let us first outline some essential attributes of

Diagram 4


Application of Theory through Background Hypotheses and Operationalizations
Interpretation of theoretical concepts through background hypotheses
Hypothesis deduced from theory
Interpretation of theoretical concept
Integration/ separation of universities and technological schools
Equalization/ differentiation of estates
Integration/ separation of groups of intelligentsia (scholars, technologists)
Integration/ separation of theoretical and practical disciplines
Theory
Interpenetration
Technology
Technology as theory application
Extent of transferability of technological inventions to different realms of problems

science and technology and some of their causes in China, India and Hellenism.

4.1 Science and Technology outside of Modern Western Culture

4.1.1 China

In China we find technical instruments of an extremely sophisticated level. In this respect, China by far surpasses the West before the turning point of the Renaissance. But there is no systematic industrial utilization of technology and a remarkable accommodation of technical problem solving to magical think-

ing, as expressed in geomantics. Conceptual abstraction is not particularly developed. Technical problem solving lacks the theoretical generalization that would have counteracted magical thinking. There is also merely technical experimentation but no rational experiment. In general, what we have is an accommodation of thinking to practical interest and magical experience.

The shaping of culture by the class of Confucian literati officials has to be seen as the basic reason for the characteristics shown by technology in China. This was an educated, aristocratic ruling class engaged in practical administration. It had no need of intellectual abstraction, rejected specialized training and downgraded economic activity. The economic sphere itself remained without ethical and universalizing control and was a domain of utilitarianism. The peculiar structure of Chinese society pushed technology into the realm of practical administration and utilitarianism without the counteraction of controlling and generalizing factors (Weber, 1972a: 414-416, 435-443, 481-484; Needham, 1954, 1969).

4.1.2 India

India displays highly-developed abstract thought, procedures of logical proof and mathematics as well as extraordinary technical inventions. It is characterized by the high degree of specialization of various disciplines and skills, but it lacks the unification of these achievements. Technical problem solving occurs without theoretical generalization, logical proof and systematic experience, and these activities are carried out without technical specification. Although the relevant components exist they are not combined in rational experiment.

The separation of specialized professions as a result of the caste system played a decisive (and causal) part in this mutual isolation of the particular forms of knowledge. Each caste had its own particular ethic and its own technical rationalization. The leading intellectual stratum, the brahmins, tended, due to its privileged position, toward abstract intellectualism. They were, nevertheless, separated from the execution of political authority, which lay in the hands of the ksatriyas. A unification of pure theory and practical technical experimentation was unthinkable in this context (Weber, 1972b: 134-147, 162-169; Zimmer, 1956).

4.1.3 Hellenism

No culture has developed conceptual and theoretical abstraction as much as Hellenism. It was here that the logic of proof emerged that is still of binding character for us today. Yet in Hellenic culture, technical problem solving and empirical experience are remarkably undervalued when compared with abstract thinking and discursive reasoning. The gap between these realms of knowledge is only bridged by their reconciliation in a graduated hierarchy. A broad conception of technology as the application of general theory and of

systematic experience as in rational experiment is lacking. The development of abstraction and logical proof was influenced very significantly by the structuring of social interaction through the dialogue in the polis. The sophists had reduced the dialogue to mere rhetoric. Only the great philosophers, Socrates, Plato, Aristotle, unified discursive argumentation with the need for knowledge and meaning. A unification of theoretical abstraction with practical, technical problem solving was however not achieved due to the separation of, on the one hand, the philosophers from practical problem solving and, on the other, of the distinguished, politically active citizens from the activities of the artisans and the merchants (Weber, 1973: 596; Jaeger, 1945; Voegelin, 1957; Ben-David, 1971: 33-44).

4.2 The Emergence of Modern Science and Technology in the Italian Renaissance of the 15th and 16th Centuries and in 17th Century England

4.2.1 The Italian Renaissance in the 15th and 16th Centuries

The Italian Renaissance was the birthplace of rational experiment and the application of theory to the solution of technical problems. We have in 1455 the invention of the art of printing by Johannes Gutenberg, an urban patrician inspired by scientific spirit but equally devoted to handicraft and commerce. There is also the Copernican shift from the geocentric to the heliocentric world view (1543-1640). What Copernicus, Kepler and Galileo had in common was that they pursued theory, experiment and the solution of technical problems simultaneously. Galileo's achievement was his resistance to the official ecclesiastical theory of the graduation of truth and his insistence on a single truth ranging from theological abstraction down to technical experimentation.

The decisive factor in this innovation must be seen in the formation, for the first time, of scientific communities. These grew from an intensification of initially loose contacts and brought together representatives of quite different forms of knowledge construction: artists, architects, engineers, artisans and scholars, thus enabling them to work with one another. Here was a place for the mutual penetration of the capacities of empirical experimentation and rational abstraction. An essential precondition for this development was the equalization of estates and the emergence of a general estate of citizens in the medieval city, a process to which the religious universalism of Christianity also contributed its share. Different social groups were able to associate freely and work together with equal rights. But in Italy this process was terminated by the renewal of the differentiation of estates, the re-aristocratization of education, which was alienated to the training of specialist skills, and the reconciliation of theological *truth* and mere scientific *probability*, a reconciliation enforced by the Church in the trial of Galileo (Weber, 1973: 595-598; Ben David, 1971: 45-74; Boas, 1970; Butterfield, 1965; Crombie, 1971; Hall, 1959; Koyré, 1968; Nelson, 1968; Whyte, 1962; Zilsel, 1942b).

4.2.2 England in the 17th Century

The gap that still existed between the constitution of meaning, normative culture and theoretical abstraction on the one hand, technical problem solving and economic action on the other, was bridged in England in the 17th century and the interpenetration of these different social contexts advanced to a much higher level. The greater interpenetration of the different components of knowledge and action has to be explained by the linking of the different orientations in scientific communities, for example in the famous *Royal Society* (1662). Artisans, engineers, scholars, merchants, entrepreneurs, politicians, and the rising profession of scientists collaborated in the scientific communities. Puritanism replaced the Catholic compromise and reconciliation between theological abstraction on the one hand and empirical science, technology and utilitarianism on the other with their mutual penetration.

The Puritan scientists sought God's universal natural laws through empirical science, and this included their utilization for practical concerns. Furthermore, the new culture was at the same time religious, scientific, technological and economic and it became increasingly rooted in a societal community embracing the old aristocracy and the new bourgeoisie and claiming a universality that gave it potential inclusiveness for all societal groups, regardless of how complete its realization was or not. But after the scientific peak reached in the mechanics of Newton and Boyle in the 17th century, science stagnated into an amateur status, because there was no institutionalization of the scientist as a cultural carrier in the universities. Instead the focus of attention shifted to the specialized production of technical instruments. An instructive example is the history of the steam engine. From it we can see that it required not only the technical model but also economic investment, continuous practical experimentation and scientific generalization until the plans of Denis Papin (1690), the patent registration of Thomas Savery (1698) and the first machine of Thomas Newcomen (1712) eventually led to the steam engine of James Watt (1775). And it was another 10 years before Watt completed work on his invention. In James Watt we have a particularly good example of the concurrence of scientific generalization, economic investment, and practical experimentation. He was a constructor of mathematical instruments, received the necessary financial resources through his association with the entrepreneur Boulton, and discovered the necessary materials and technical details only in the process of practical experimentation (Merton [1938] 1970; Barber, 1970; Ben-David, 1971: 66-87; Butterfield, 1965; Crombie, 1971; Finch, 1961; Hill, 1964; Kearney, 1964, 1965; Koyré, 1968; Rabb, T. K., 1965; Rossi, 1970; Scherer, 1965; Zilsel, 1942a, 1942b, 1945).

4.3 The Further Development of Modern Science and Technology

I will now move on to the development of modern science and technology in France, Germany and the USA in the 18th, 19th and 20th centuries respec-

tively, concentrating on the following factors: the separation or interpenetration of

— intellectual strata, science and society,
— technical intelligentsia and society,
— research and teaching,
— theoretical and practical disciplines,
— scientific research and economic mobilization of resources, pure and industrial research.

4.3.1 France in the 18th Century

The center of scientific advance switched from England to France in the 18th century. Here it was chemistry that expanded, mainly through the contributions of Lavoisier and Dalton and the 'pneumatic revolution'. We can explain the development of science in France by the socially binding establishment of the natural sciences. This institutionalized the continued integration of the various components of knowledge in a comprehensive, new discipline: modern science. The process was accelerated by the concentration of scientific activities in the *Académie des Sciences* (1666), which was founded shortly after the *Royal Society*. The new science was extensively supported by the ancien régime and subsequently also by Napoleon. But the founding of the grandes écoles as specialized *educational* institutions and the institutionalization of scientific research in special academies or its amateur and private pursuit by teachers resulted in a clear separation of theoretical and practical disciplines, of teaching and research. This structure was not favorable to the professionalization of the scientist as a cultural carrier, nor to the theoretical anchoring of technology. At the same time there existed a considerable separation of the purely intellectual strata and the technical intelligentsia from one another and from other societal groups. In this dimension there was also insufficient interpenetration of technology with science and intellectual culture and of these with the other spheres of society (Ben-David, 1971: 88-107; Hahn, 1971).

4.3.2 Germany in the 19th Century

In the 19th century Germany took over the leading role in scientific and technological development. Particular achievements were recorded in the fields of chemistry, physiology, psychology and in the humanities.

This upswing was preceded by a reform of Prussia's universities. This was a result of the alliance between the humanistic intellectual stratum of German idealism and Prussian absolutism, an alliance in which the idea of the 'culture state' (Kulturstaat) figured prominently. The reform of the universities had as its decisive innovation the integration of research and teaching, which made possible for the first time the institutionalization of the scientist as a cultural carrier, thus providing for the continuing integration of different components of knowledge in science. This was complemented by the corresponding institu-

tionalization of research laboratories in the universities. Here, totally new link-ups between experience, technology, logic and theory and the mediation of professional orientation became possible. Later on, this interlocking was strengthened by research laboratories in the chemical industry and these held a leading position in the world for quite some time. But this constellation of factors favorable to the societal interlocking of science and technology was weakened by counteracting factors. To these belonged the separation of theoretical and practical disciplines through the founding of specialized technical institutions, the increasing displacement of research from the universities to research institutes (Kaiser Wilhelm Society, Max Planck Institutes), the declining integration of pure research at universities and research institutes with industrial research, the separation of the humanistic intellectual stratum from natural science, technology and society and of the technical intelligentsia from the other spheres of society. A peculiarity of German society still in evidence today is the degree of antagonism between the humanities (Geisteswissenschaften) and science (Naturwissenschaften). These conditions interfere with the interpenetration of science, technology and other societal spheres. They do not allow for solutions to the conflict between science and technology and morals, which are so vital these days (Ben-David, 1971: 108-138; Ringer, 1969; Schelsky, 1971).

4.3.3 The USA in the 20th Century

The leading role in science and technology passed on to the United States in the 20th century.

This process had its beginnings in a reform of the universities around the end of the 19th century modelled on the then world leaders, the German universities. The reform did not replicate the German original but exceeded it through a number of innovations. The introduction of graduate training opened the way for the simultaneous institutionalization of the integration of research and teaching, the professionalization of the scientific researcher as a cultural carrier on a new level and the inclusion of mass education in the universities. The inclusion of undergraduate training in the universities allowed for a closer linking of scientific orientation, normative-cultural and communal anchorage. Similarly, the integration of the professional schools in the major universities resulted in a greater interpenetration of theoretical and practical disciplines, of scientific and technological orientation and normative-cultural and communal commitment. The professions now form a zone of interpenetration of the different orientations. In addition, there exists a more extensive link between intellectual culture and science, technology and the general public. Interdisciplinary research institutes facilitate the interpenetration of different orientations. This is particularly noticeable in the emergence of disciplines such as statistics, social sciences, biophysics, biochemistry, sociobiology etc. that combine different orientations. Finally, closer collaboration between pure university research and industrial research favors the linking

of theory, technology, economic investment and practical goal attainment (Ben-David, 1971: 139-168; Hirsch, 1968; Parsons and Platt, 1973; Riesman and Jencks, 1968; Smelser, 1973, 1974).

Conclusion

More than all its predecessors, the example of the world's leading scientific and technological nation shows us that it is not mere social differentiation and rationalization in separated spheres according to some inner laws but the interpenetration of science and technology and their interpenetration with their societal environment that mark the most highly developed science and technology. And this fact is of crucial importance both for sociological theory and for practical action. The emergence and development of modern science and technology is far more a case for a theory of interpenetration than for a theory of the pure differentiation and rationalization of spheres according to their own internal laws.

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